The Effect of Small-Scale Ocean Fluctuations on Acoustic Propagation

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LONG-TERM GOALS

To connect the results of sound transmission and scattering experiments to known or hypothesized structures within the hydrosphere, such as internal waves or microstructure, with account taken of ocean anisotropy, inhomogeneity, and the sound channel.

OBJECTIVES

To develop both analytical and numerical techniques that will be of value in future comparisons between experiment and theory, and that will facilitate the monitoring of the large-scale structure of the internal-wave field and other ocean processes with acoustics.

A secondary objective is to access the broader community of scientists working on wave propagation in random media, and to both learn and teach new techniques within that community.

APPROACH

The analytical techniques we use revolve around extensions of ray theory, especially by means of the path-integral method. These techniques allow the derivation of expressions for many important observables in ocean acoustics in terms of ordinary integrals along the rays. The integrands vary with the observable, but are functions of the internal-wave spectrum, such as correlation lengths, and ray behavior: for example, depth and angle.

Solutions to the parabolic wave equation representing acoustic propagation through a field of internal waves can be found by numerical simulation by use of the Fast Fourier Transform. In order to represent pulse propagation, a multi-frequency approach is taken.

Our approach to related areas includes discussions with those working on optical propagation through atmospheric turbulence, seismic-wave propagation through a heterogeneous earth, and radio-wave propagation through interplanetary plasma and the ionosphere.

WORK COMPLETED

An important quantitative comparison between experiment and calculations of internal-wave effects on acoustic propagation involved the 1000-km, SLICE89 experiment in the north Pacific. A pulse was transmitted from 800-m depth and received on a vertical array. The following figure shows simulations of the received signal in four cases: the upper left in the case of no internal waves, and the

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14. ABSTRACT
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15. SUBJECT TERMS

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other three corners each have a different realization of internal waves. The continuous wavefront is bent into many wavefront segments by the action of the sound channel over 1000 km. The observed fattening of the late-arriving portion of the pulse, as well as the smaller variability of arrival time with depth observed in the earlier wavefront segments, agree well with the same effects observed in the experiment. The x-axis of each of the four subfigures is arrival time from 673 s to 677 s (these are arrivals at 1000-km range); the y-axis is depth from 0 (at the top) to 4000 m.
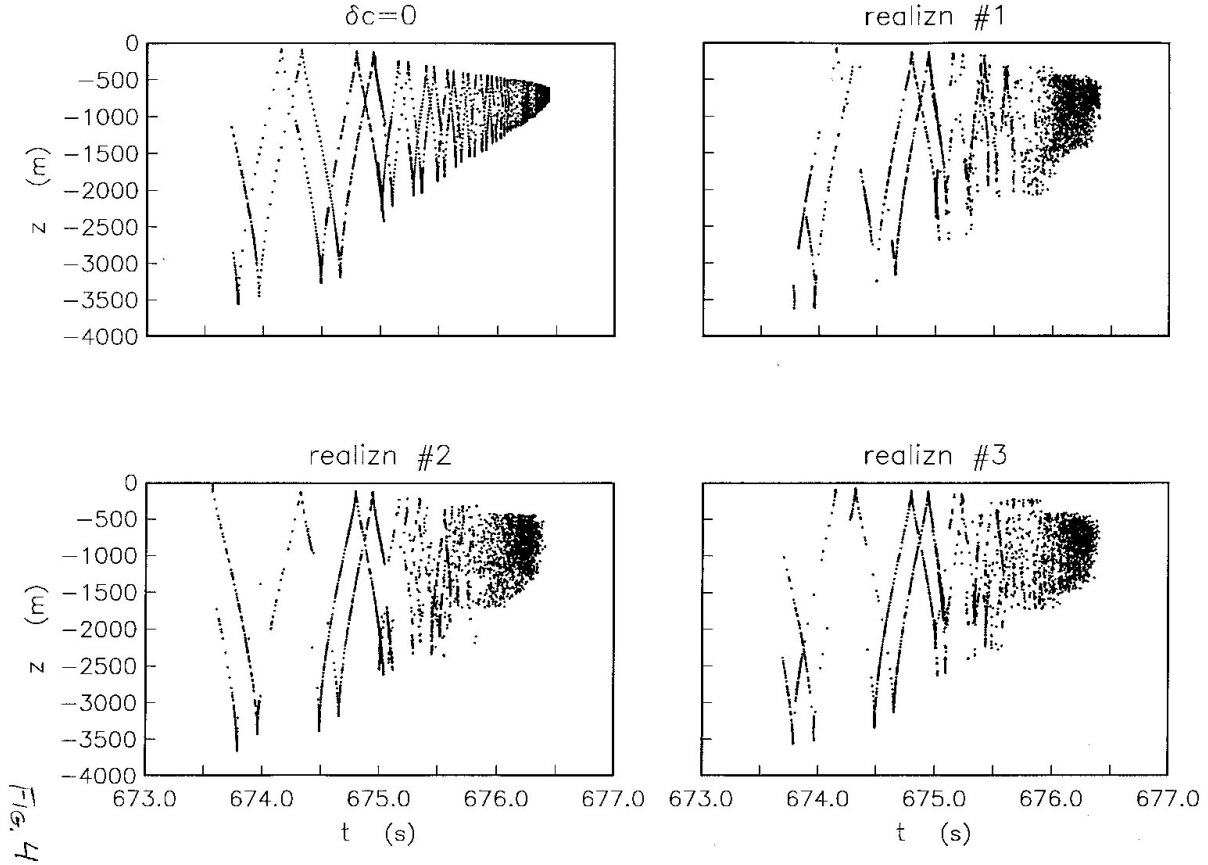

Figure 1

Since the successful comparison of many acoustic-fluctuation quantities from the SLICE89, 1000-km, acoustic experiment with predictions of path-integral theory incorporating propagation through internal waves, we have completed a variety of projects involving long-range acoustic propagation.
We developed a novel method of treating data on a vertical array to determine that observed tidal effects were in fact due to a large-scale baroclinic tide. The method was used to determine that the data were explained by an M2 baroclinic tide originating in a source region in the Gulf of Alaska. (Published in J. Phys. Oceanography)

With Jeffrey Simmen and Guang-Yu Wang, we used geometrical optics and numerical integration of the ray equation to investigate behavior of rays through an internal-wave field. We determined the effects of small scale structure, such as: the extent to which wavefronts are folded, to what extent rays become chaotic, and also in what way diffraction enters. (Published in J.A.S.A.) The top segment of

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the following figure shows the result of following an extremely dense fan of rays from a source on the axis to a receiver on the axis 1000 km away; The figure shows the path (in range, from 0 to 1000 km, and depth, from 0 to 3500 m, in the horizontal and vertical, respectively) it is seen that those rays that arrive within a few meters of the receiver are confined to nearly the same path. This shows that ray tubes still have a meaning in the presence of internal waves. The center segment of the figure magnifies the central region of the top figure, showing ranges from 500-700 km. It is seen that while each ray moves between depths of 500 to 2500 m, at each range, all of the rays are contained within a 500-m interval.
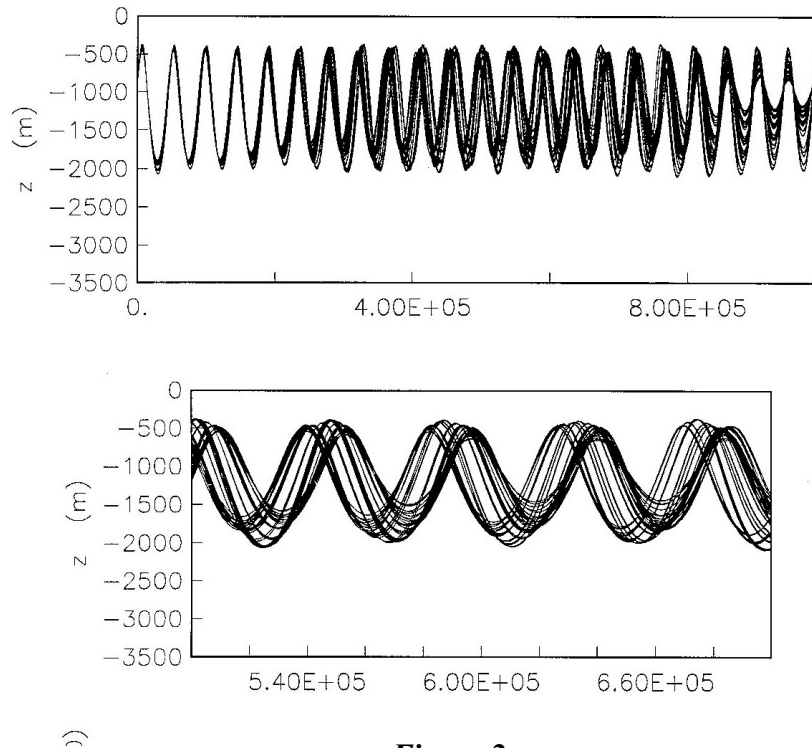

Figure 2

In collaboration with Harry deFerrari and his group, we analyzed the behavior near a caustic in a 270-km, 400-Hz, acoustic experiment to show that, although ray theory nominally breaks down at caustics, corrections can be applied to successfully compare with experiment. (Published in J.A.S.A.)

Work in collaboration with John Colosi of SIO was carried out to determine internal-wave effects at multi-megameter ranges. This involved PE simulations, and analysis in terms of both modes and wavefronts (rays). The mode analysis shows that mode coupling due to internal waves generates large fluctuations in the travel time of higher modes in long-range tomography experiments. This implies that the use of modes higher than the first few in determining ocean processes will be dramatically hampered by large fluctuations due to internal waves. At the same time we have found that the travel-time fluctuations for wavefronts (rays) are very much less, suggesting that the use of wavefronts is much to be preferred in a tomography experiment. Comparison of the PE simulation results with calculations based on the path-integral technique using the CAFI program shows that the CAFI calculations (which require much less computer time) are accurate to within about 30\%, and both methods show that the quantities of interest (angular spreading, arrival-time spreading, and arrival-time

bias) scale according to the path-integral formulas. We also collaborated with the NPAL group to compare these results with data from a 3252-km propagation experiment. (Published in J.A.S.A.)

With regard to tomography of the internal-wave field, work with the Levitus data base of sound-speed profiles over the world's oceans, allowed the formation of an "effectiveness" factor, F, for observing internal-waves through acoustic fluctuations. That is, a larger F implies a larger acoustic effect for a given internal-wave energy. Plots of F show the regions of the world in which it is easier or more difficult to measure internal waves with acoustics. Thus a map of F is of use to experimenters as one input into planning the location of an experiment. This work comprised a Master's Thesis for Kimberly Noble, and was published in J.A.S.A.)

Another important contribution to the field was the publication of the formulas used in the CAFI code to calculate acoustic fluctuations on an arbitrary ray induced by internal waves. Done in collaboration with Galina Rovner of the Marine Physical Laboratory at SIO, this was published in J.A.S.A., and has already been used by a number of researchers for comparing to experimental data.
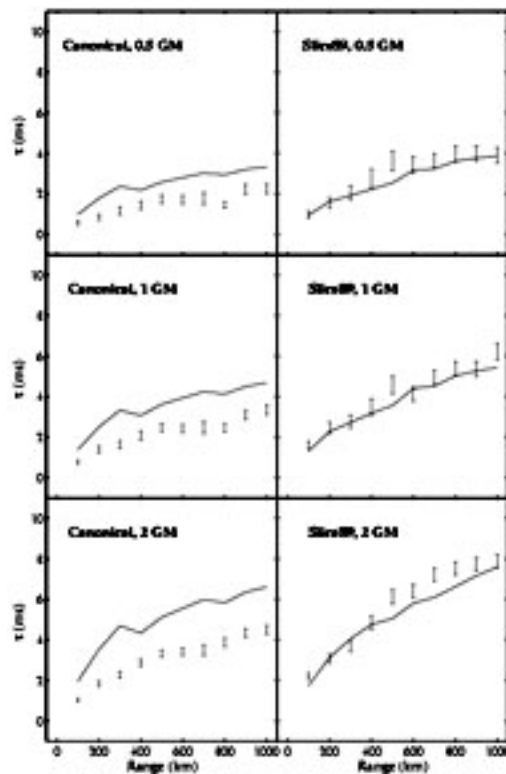

Figure 3

The most recent work, done with Michael Vera while he was a graduate student, involved two separate projects, both published in J.A.S.A. The first tested the effect of the time-evolution of internal waves during the passage of an acoustic wave over megameters. The goal here was to quantify an effect that was expected to be small because the acoustic waves travel very much faster than the internal waves. The results show that internal-wave time evolution is about as important as moving the source or receiver by 100 m. The second project for the first time compared the predictions of the analytic integrals calculated in CAFI with results obtained by parabolic-equation numerical simulation. Differences were observed, but factor-of-two agreement was obtained, showing that CAFI could be a

rough guide for planning purposes. The figure above has six parts; the three on the left use the canonical sound channel and the three on the right use the SLICE89 sound channel. The top, middle, and bottom rows use internal-wave strengths of 0.5, 1.0, and 2.0 times the reference Garrett-Munk level. The line in each figure comes from CAFI calculations, and the points with error bars come from numerical simulations involving many propagations through 1000 km of different realizations of the internal waves. In each panel, the vertical axis is rms travel-time variation from 0 to 10 ms and the horizontal axis is range from 0 to 1000 km. The agreement for rms travel time is within 30 percent or better.

RESULTS

During FY05, effort was directed in other directions than publishing papers. Attendance at several meetings provided venues for extensive discussions with other workers, such as Mel Briscoe, John Colosi, Frank Henyey, Bill Kuperman, Jim Lynch, Peter Muller, Michael Vera, and Peter Worcester. Continuous discussion goes forward on rays and modes, linear internal waves and solitary waves, deep and shallow water, and other issues. The meetings included the Vancouver ASA meeting, and the associated NPAL meeting in Semiahmoo, WA. An invited talk at the Univ. of Concepcion in Chile provided the opportunity to discuss common interests in ocean-acoustic experiments. Their seismology group does moored experiments in the ocean off the coast of Chile that might provide a platform for acoustic experiments to study internal waves in that part of the ocean.

IMPACT/APPLICATIONS

The use of CAFI for the calculation of internal-wave effects on acoustic fluctuations has been made easier by its availability via the web, and several researchers presented results based on such use at the NPAL meeting in Semiahmoo, WA. It is hoped that the published results on the F factor will provide useful input to experimenters in planning their experiments.

TRANSITIONS

Connections to the areas of research in wave propagation through random media continue along a number of paths. One community of great relevance is that devoted to optical propagation through atmospheric turbulence. This PI and some of his students published papers during the last 15 years on this topic, in the J. Optical Society of America. That work involved numerical simulation of the parabolic equation through three-dimensional turbulence, so that there are two directions transverse to the direction of propagation. Work in the ocean on three-dimensional propagation is being started.

A recent connection has been established with astrophysicists working on radio waves propagating through interplanetary plasma. (An example is the radio signal from the Voyager spacecraft.) Work done by this PI and his group in the 1980's dealt with the two-frequency intensity coherence function, and the astrophysical community has used that work in further developments. (for example, Professor Jeremy Goodman of Princeton University)

RELATED PROJECTS

The main closely related project is the NPAL group's effort, which spans experiment in the North Pacific and associated theory. Their web site is: http://npal.ucsd.edu/index.htm

HONORS/AWARDS/PRIZES

The PI received a certificate honoring 25 continuous years of membership in the Acoustical Society (23 years as a Fellow).